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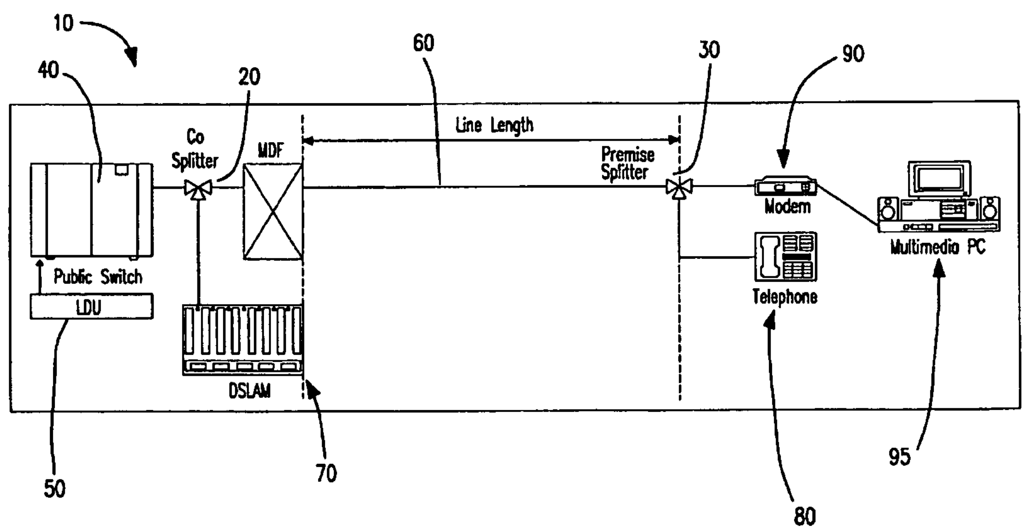
(54) Title: METHOD AND APPARATUS FOR TERMINATION DETECTION IN AN ADSL ENVIRONMENT



(57) Abstract: A method and apparatus that will detect the presence of terminations in an ADSL environment is presented. The presently disclosed method and apparatus applies a slowly ramped voltage to the subscriber loop while measuring the current flow. The ramped voltage is able to pass through the inductors. The rate of current flow is discernible as the zener diodes of the Half Ringer, the Premises Splitter, and any Electronic Ringer start to conduct. Thus the detection in time (voltage) of devices that may be on the line under test is achieved. By analysis of a graph of the current in the line as the ramped voltage is applied, changes in the graph provide an indication that a termination is present. The location of the change in current with respect to the applied voltage provides an indication of the type of termination detected.

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TITLE OF THE INVENTION

Method and Apparatus for Termination Detection in an ADSL Environment

BACKGROUND OF THE INVENTION

Telephone companies are offering ADSL (asynchronous digital subscriber loop) services to qualified subscribers. With the advent of ADSL, new network devices are being deployed on the subscriber's loop. ADSL introduces splitters at both the Central Office (CO) end of the subscriber loop and the Customers Premises end of the subscriber loop. The presence of splitters on a line needs to be detected in order to properly characterize the line. These splitters typically comprise a complex 3 to 8 pole passive filter which is in series with the subscriber loop. The CO splitter has a signature that appear as a polarized DC fault (resistive). The premises splitter is in effect a modified half ringer and as such is not polarized. The premises splitter has an AC type signature in that it has both conductive and susceptive components. These signatures have been standardized through the ITU standards committee in the T1.413 document that standardizes ADSL functionality.

In order to achieve these splitters, inductors are used. These splitters are designed to be benign to Plain Old Telephone Service (POTS) interaction, therefore standard line tests such as demand tests, routine tests, and fault location tests are not an issue as long as each splitter has a unique identifying signature. If the signatures can be identified, the effects of the splitters (resistance, conductance and susceptance) can be removed, rendering these splitters transparent to the test system. This is not the case with nonstandard line tests. One such nonstandard line test is the Electronic Ringer Detection (ERD) sequence. This test uses a series of square wave pulses at different amplitudes to determine the presence or absence of both electronic ringers and half ringer type devices. An inductor will suppress the higher frequencies of a square wave to a point where the square wave will become distorted. Testing has shown that the ERD technique becomes counterproductive on ADSL equipped lines. That is, non-repeatable results occur in two or more successive tests. It is this non-repeatability that makes the pulse technique on ADSL equipped lines both useless and counter-productive. It would be desirable to have

an apparatus and a method for reliably and repeatably detecting various terminations of a line in an ADSL environment.

SUMMARY OF THE INVENTION

With the foregoing background in mind, it is an object of the present invention to provide a method and apparatus that will detect the presence of terminations in an ADSL environment. The presently disclosed method and apparatus applies a slowly ramped voltage to the subscriber loop while measuring the current flow. The ramped voltage is able to pass through the inductors. The rate of current flow is discernible as the zener diodes of the Half Ringer, the Premises Splitter, and any Electronic Ringer start to conduct. Thus the detection in time (voltage) of devices that may be on the line under test is achieved. By analysis of the current in the line as the ramped voltage is applied, changes in the value of the current provide an indication that a termination is present. The location of the change in current with respect to the applied ramped voltage provides an indication of the type of termination detected.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention will be better understood by reference to the following more detailed description and accompanying drawings in which

Fig. 1 is a block diagram of an ADSL environment;

Fig. 2 is a schematic diagram of an apparatus for determining terminations in an ADSL environment;

Fig. 3 is a scope trace of a voltage waveform and resultant current waveform;

Fig. 4 is a scope trace of the voltage waveform and a differentiated current waveform;

Fig. 5 is a scope trace of the current waveform and the differentiated current waveform ;

Fig. 6 is a schematic diagram of an apparatus for determining terminations in a second ADSL environment;

Fig. 7 is a scope trace of a voltage waveform and resultant current waveform;

Fig. 8 is a schematic diagram of an apparatus for determining terminations in a third ADSL environment;

Fig. 9 is a scope trace of a voltage waveform and resultant current wave form; and

Fig. 10 is a schematic of a fourth ADSL environment.

DESCRIPTION OF THE PREFERRED EMBODIMENT

With the introduction of new services such as ADSL, it may not be possible to have any foreknowledge if the CO of a telephone company will be equipped to handle the provision of these new services to subscribers. This means that standard test systems could be fooled into thinking there are ringers on a subscribers line if the line under test is equipped with splitters and a half ringer but has no phone. For this reason it has become necessary to augment the current demand test sequences with a modified DC6 algorithm to detect the presence or absence of a potential CO Splitter, and to replace the pulse technique utilized for electronic ringer detection with a new technique. The new technique will be required as part of the demand test sequence to detect network equipment before any cable and ringer analysis is performed. This is because the splitters and half ringer can add enough Tip to Ring capacitance to mimic a standard (mechanical) ringer.

ADSL adds a CO splitter and a premises splitter in series with the line. The CO Splitter is defined as a polarized DC fault. The use of a signal diode (1N4007) and a zener diode (36V) provide both polarity sensitivity and a threshold of conduction that falls outside the realm of ADSL signals. Present test systems utilize a DC5 algorithm that solves the standard 5G-fault model but are based on the assumption that the Tip to Ring conductance will be the same as the Ring to Tip conductance. In most instances of a fault condition, this is true. This assumption requires only three drive conditions to be applied to a line under test to solve for most faults. This helps to keep test times to a minimum. Currently deployed test systems supply a drive configuration that forces a current only one way through the Tip-Ring conductance. An additional drive configuration needs to be added to allow the determination of opposing currents flowing through Tip and Ring.

For DC fault detection, known test systems utilize the following drive sequence in a Demand Test to detect current flow:

1) GDT (ground on Tip, Drive (battery) on Ring, measure Tip current);
2) DDT (Drive (battery) on Tip, Drive (battery) on Ring, measure Tip current);
3) DDR (Drive (battery) on Tip, Drive (battery) on Ring, measure Ring current);
4) GGT (ground on Tip, ground on Ring, measure Tip current); and
5) GGR (ground on Tip, ground on Ring, measure Ring current).

For the CO splitter signature, current can only flow if the Ring side is more positive than the Tip side. None of the five measurements performed by known test systems allow for this condition. Therefore these presently employed test systems cannot

detect a properly installed CO Splitter. An additional drive, either DGT (drive Tip, ground Ring, measure Tip) or DGR (drive Tip, ground Ring, measure Ring) will allow current to flow in the CO Splitter (Ring at ground potential is more positive with respect to Tip which is being driven at about negative 50 volts).

Referring now to Fig. 1, an ADSL environment 10 is shown. The environment includes a CO splitter 20 located in the central office in series between the public switch 40 and the subscriber loop 60. The splitter also is in communication with a Digital Subscriber Line Access Multiplexer (DSLAM) 70. At the premises end of the loop a premises splitter 30 is shown . The premises splitter 30 is connected in series between the subscriber's telephone 80 and the subscriber loop 60. Also connected to the splitter is an ADSL modem 90 and computer 95. A test unit 50 is connected to the public switch 40 and is used to characterize the line 60 and any network devices on the line from the public switch 40 to the subscriber premises.

Referring now to Fig. 2, a schematic diagram of the apparatus 100 for determining the presence of terminations in an ADSL environment is shown. The test apparatus 100 comprises a ramped voltage source 110, a ring side source resistance 120, a tip side source resistor 130, a differential amplifier 140, a differentiator 150 and a gain stage 160. The schematic also includes circuitry for simulating the effects of the line 170 (also known as an artline), the CO splitter 180, the premises splitter 200, a half ringer 190 and an electronic ringer 220

In a particular embodiment a ramped voltage (0 to ±100V from 0 to 1.0 seconds) is provided by voltage source 110. The ramped voltage is applied through the Ring side source resistor 120 (in this case a resistor having a value between 100 ohms and 20K ohms). The Tip side is grounded through the tip side source resistor 130 (again, a resistor having a value between 100 ohms and 20K ohms) of the measurement unit 50. The current flow is measured by monitoring both sides of the ring side source resistor 120. The differential amplifier 140 subtracts the measured voltage from the source voltage and produces a current waveform at the output of the differential amplifier 140. The output of the differential amplifier 140 may be fed to a differentiator 150 and the output of the differentiator 150 may be provided to a gain stage 160.

Referring now to Fig. 3, a scope trace 250 of the measured current 270 and applied ramped voltage 260 are shown. The vertical lines 252 and 254 indicate a turn on or breakover of the Half Ringer and the Premises Splitter respectively. The breakover of the Electronic Ringer can also be seen at point 256. Note the levels of the ramped input voltage when the terminations turn on. The Half Ringer starts to conduct current when the drive voltage is approximately -4.1 volts, the Premises Splitter starts to conduct when the

drive voltage is approximately -9.7 volts and the Electronic Ringer starts to conduct when the drive voltage is approximately -34 volts. Since these breakover values are approximately 2.7v (for the zener of the half ringer simulation circuit 190), 6.8v (for the zener of the premises splitter simulation circuit 200) and 27.7v (for the zener of the electronic ringer simulation circuit 220), these values imply a delay in the circuit that slows down the drive voltage before it gets to the output of the line. This makes sense as the line itself is an RC circuit. Note also that the Half Ringer breakover 252 and the turn on of the Electronic Ringer are easily seen. The circuit before each of these events has more or less settled and any change in current flow is evident. In contrast to these breakover points, the breakover of the Premises Splitter 254 is not so obvious. This is because the Half Ringer capacitor has not fully charged. Accordingly, the additional current flow due to the capacitor in the Premises Splitter is not as evident because of abundant (relatively) current already flowing in the circuit.

One way to highlight the changes in current to make them easier to detect is to take the differential of this current waveform. The changes in current then become much more evident. Referring now to Fig. 4, the differential of the current waveform 320 (measured at the output of differentiator 150 or amplified and measured at the output of gain stage 160) is compared to the drive voltage 310. The current changes 330, 340 and 350 are now "exaggerated" and can be more readily detected. Similarly, the scope trace 360 of Fig. 5 shows the differential of the current waveform 320 and the output of the differential amplifier waveform 270.

A description and analysis of detection of a Half Ringer using the presently disclosed method and apparatus follows. This analysis will be done using an 18 Kft line. Using a turn on voltage of 2.4 volts and a forward drop of 0.5 volts for the zener diodes of the Half Ringer, the time that the output voltage of the line is equal too -2.9 volts will be determined mathematically.

$$T := 0.5 \qquad R1 := 9.676649 \cdot 10^{1} \qquad P1 := -9.676649 \cdot 10^{1}$$

$$Vo(t) := 60 \cdot \frac{R1}{P1 \cdot T} \cdot \left(t + \frac{1}{P1} - \frac{1}{P1} \cdot e^{P1 \cdot t} \right)$$

$$-2.9 = 60 \cdot \frac{9.676649 \cdot 10^{1}}{-9.676649 \cdot 10^{1} \cdot 0.5} \cdot \left(t + \frac{1}{-9.676649 \cdot 10^{1}} - \frac{1}{-9.676649 \cdot 10^{1}} \cdot e^{-9.676649 \cdot 10^{1} \cdot t} \right)$$

$$t = \begin{bmatrix} 3.41203148250621 10432 \cdot 10^{-2} \\ -1.64966323181347 59681 \cdot 10^{-2} \end{bmatrix}$$

The negative root is obviously not correct so the answer is:

$$t := 3.41203148250621 10432 \cdot 10^{-2}$$

Now the input voltage at 34.12 milliseconds is determined

$$Vi(t) := -60 \cdot \frac{t}{T}$$

$$Vi(t) = -4.094438$$

This mathematical analysis shows that a change of current in the network that contains a Half Ringer should occur at about 34.12 milliseconds and when the input voltage is about -4.1 volts. In the scope trace shown in Fig. 3, the oscilloscope showed a breakover change in current at about 34.3 milliseconds and an input voltage of about -4.12 volts. The math validates the simulation.

A similar analysis will be done for detecting a premises splitter. Referring to Fig. 6, circuit 400 is shown. Circuit 400 differs from circuit 100 of Fig. 2 only in that the Half Ringer termination has been removed. Using a turn on voltage of 6.4 volts and a forward drop of 0.5 volts for the zener diodes of the Premises Splitter, the time that the output voltage of the line is equal to -6.9 volts will be determined.

$T := 0.5 \qquad R1 := 9.676649 \cdot 10^{1} \qquad P1 := -9.676649 \cdot 10^{1}$

$$Vo(t) := 60 \cdot \frac{R1}{P1 \cdot T} \cdot \left(t + \frac{1}{P1} - \frac{1}{P1} \cdot e^{P1 \cdot t}\right)$$

$$-6.9 = 60 \cdot \frac{9.676649 \cdot 10^{1}}{-9.676649 \cdot 10^{1} \cdot 0.5} \cdot \left(t + \frac{1}{-9.676649 \cdot 10^{1}} - \frac{1}{-9.676649 \cdot 10^{1}} \cdot e^{-9.676649 \cdot 10^{1} \cdot t}\right)$$

$$t = \begin{bmatrix} 6.78195562867543840502 \cdot 10^{-2} \\ -2.23928122482198799 16 \cdot 10^{-2} \end{bmatrix}$$

The negative root is obviously not correct so the answer is:

$t := 6.78195562867543840502 \cdot 10^{-2}$

The input voltage value at 67.82 milliseconds is determined

$$Vi(t) := -60 \cdot \frac{t}{T}$$

$$Vi(t) = -8.138348$$

Referring to the scope trace 450 of Fig. 7 the applied ramped voltage 460 and resulting current 470 are shown From the scope trace 450 it can be seen that the simulation results are as the calculations predicted. The time at which the Premises Splitter starts to conduct is 67.99 milliseconds for the simulation versus 67.81 milliseconds for the calculation. The drive voltage is at -8.16 volts for the simulation versus 8.14 volts for the calculation. The effects of the Half Ringer have been removed and the math still holds. Again, this will change when the analysis takes into account more than one termination device on the line under test (here the drive voltage has not yet reached a level to where the electronic ringer will start to conduct).

Next, an analysis of the detection of an electronic ringer will be discussed. Referring now to Fig. 8, the circuit 500 is shown. Circuit 500 differs from circuit 400 of Fog. 6 only in that premises splitter has been removed. The simulation uses a model with a 27.0 volt zener voltage although it is marked as 27.7 volts on the schematic. The 27.0 volt value is to be used for the following calculations.

Referring now to Fig. 9, scope trace 550 shows the applied voltage 560 and the resulting current 560. The simulation shows a breakover time of about 243.1 milliseconds and a drive voltage of about -29.17 volts. Using a turn on voltage of 27.0

volts and a forward drop of 0.7 volts for the zener diodes of the Electronic Ringer, the time that the output voltage of the line is equal to -27.7 volts will be calculated.

$$T := 0.5 \qquad R1 := 9.676649\cdot10^{1} \qquad P1 := -9.676649\cdot10^{1}$$

$$Vo(t) := 60\cdot\frac{R1}{P1\cdot T}\cdot\left(t+\frac{1}{P1}-\frac{1}{P1}\cdot e^{P1\cdot t}\right)$$

$$-27.7=60\cdot\frac{9.676649\cdot10^{1}}{-9.676649\cdot10^{1}\cdot0.5}\cdot\left(t+\frac{1}{-9.676649\cdot10^{1}}-\frac{1}{-9.676649\cdot10^{1}}\cdot e^{-9.676649\cdot10^{1}\cdot t}\right)$$

$$\begin{bmatrix} .24116748929917165723 \\ -3.3912648297369510 47\cdot10^{-2} \end{bmatrix}$$

The negative root is obviously not correct so the answer is:

$$t := .24116748929917165723$$

The input voltage value at 241.12 milliseconds is determined

$$Vi(t) := -60\cdot\frac{t}{T}$$

$$Vi(t) = -28.940099$$

The simulation shows that the Electronic Ringer will start conducting at about 243.1 milliseconds when the drive voltage is at about -29.17 volts. This is very close to the 241.2 milliseconds and -28.94 volts predicted by the mathematical analysis. This is an example how the breakover time for an Electronic Ringer could be predicted, but it is usually not known what Electronic Ringer is terminating a line under test. Typically, it will not be necessary to know exactly when an Electronic Ringer breaks over, just as long as the ringers break over above a certain threshold. There are some interesting possibilities when using the ramp technique to determine Electronic Ringers. For instance, it may be possible, for the first time, to count the number of Electronic Ringers on a line and store that in the footprint for the line under test. With this information, it may be possible to increase the chances of more accurately determining inside wire faults.

Having detected occurrences of single terminations on a line, it is also necessary to determine the occurrence of multiple terminations on a line. As the line is an RC device, it is only natural that it act as a delay line to an applied voltage. This has been shown above. As long as the voltage at the output of the line is below the turn on threshold of the terminating devices, the output of the line looks into an open circuit. As

soon as a terminating device turns on (conducts current) the resulting output voltage will be slowed even more as the device turning on is more than likely another RC device. It is the interaction between the drive voltage, the line, and the turn on of the terminating devices that drives the need for another analysis.

For the analysis when there are more than one terminations on the line under test, consider the circuit 600 of Fig. 10.

The artline (18K feet) and Drive Source are shown simplified where the values are:

$Ri(prime) := 51$	The 51 ohm resistors at the end of the artline
$Ri := 2\cdot 18000 + 2\cdot 255$	The two source resistors plus the two legs of the artline
$Cg := 3\cdot 104.82\cdot 10^{-9}$	The ground capacitance of 18K foot artline
$Cb := 2\cdot 41.92\cdot 10^{-9}$	The Tip - Ring capacitance of 18K foot artline
$Ci := \frac{Cg}{2} + Cb$	The mutual capacitance of 18K foot artline

Time t1 is the time when the first (lowest breakover voltage) network termination turns on and has been calculated above. Time t2 is the time when the second (next lowest breakover voltage) network termination starts to conduct. It is this time, t2, which will be determined. It can also be said that $|Vz1| < |Vi(t)| < |Vz2|$ then $t1 < t < t2$. Vout2 must be defined for this time period. Vout2 is dependent on both Vi(t) and the interaction of the Half Ringer 610. It is this dependence that must be analyzed to be able to calculate when in time the premises termination 620 starts to conduct. First the artline:

$$Zi = 2\cdot R1(prime) + \frac{Ri}{1 + s\cdot Ri\cdot Ci}$$

Next the voltage at the far side of the half ringer (Vout2) using the assumption that the zener diode impedances are small, is determined:

$$Vout2(s)=\frac{R1\cdot\frac{1}{s\cdot C1}}{Zi+R1+\frac{1}{s\cdot C1}}\cdot Vi(s)$$

$$Vout2(s)=H(s)\cdot Vi(s)$$

Describe the transfer function, H(s):

$$H(s)=\frac{1+s\cdot(R1\cdot C1+Ri\cdot Ci)+s^{2}\cdot(R1\cdot C1\cdot Ri\cdot Ci)}{1+s\cdot(Ri\cdot Ci+R1\cdot C1+2\cdot Ri(prime)\cdot C1+R1\cdot C1)+s^{2}\cdot(R1\cdot C1\cdot Ri\cdot Ci+2\cdot Ri(prime)\cdot Ri\cdot C1\cdot Ci)}$$

which has the general form of

$$H(s)=K0+\frac{A1}{s-B1}+\frac{A2}{s-B2}$$

the impulse response of the transfer function can now be defined as:

$$H(t)=\left(A1\cdot e^{B1\cdot t}+A2\cdot e^{B2\cdot t}\right)\cdot u(t)+K0\cdot\delta(t)$$

Now convolute Vi(t) with H(t)

$$Vi(t)=k1\cdot\left(t+\frac{1}{P1}-\frac{1}{P1}\cdot e^{P1\cdot t}\right)\cdot u(t-t1)$$

$$H(t)=\left(A1\cdot e^{B1\cdot t}+A2\cdot e^{B2\cdot t}\right)\cdot u(t)+k0\cdot\delta(t)$$

First term...

$$(k0\cdot\delta(t))*(Vi(t))=k0\cdot k1\cdot\left(t+\frac{1}{P1}-\frac{1}{P1}\cdot e^{P1\cdot t}\right)\cdot u(t-t1)$$

next term...

$$\left(A1\cdot e^{B1\cdot t}*u(t)\right)\cdot(k1\cdot t\cdot u(t-t1))=k1\cdot A1\cdot\int_{t1}^{t}\tau\cdot e^{-B1\cdot(\tau-t)}d\tau$$

$$\left(A1\cdot e^{B1\cdot t}*u(t)\right)\cdot(k1\cdot t\cdot u(t-t1))=\frac{-k1\cdot A1}{B1}\cdot e^{B1\cdot t}\cdot\int_{t1}^{t}\tau\, de^{-B1\cdot\tau}$$

$$\left(A1\cdot e^{B1\cdot t}*u(t)\right)\cdot(k1\cdot t\cdot u(t-t1))=\frac{-k1\cdot A1}{B1}\cdot e^{B1\cdot t}\cdot\left(\tau e^{-B1\cdot\tau}-\int_{\tau_1}^{\tau}e^{-B1\cdot\tau}dt\right)$$

$$\left(A1\cdot e^{B1\cdot t}*u(t)\right)\cdot(k1\cdot t\cdot u(t-t1))=\frac{-k1\cdot A1}{B1}\cdot e^{B1\cdot t}\cdot\left(\tau e^{-B1\cdot\tau}+\frac{1}{B1}\cdot e^{-B1\cdot\tau}\right)\quad\text{evaluated from } \tau 1 \text{ to } \tau$$

$$\left(A1\cdot e^{B1\cdot t}*u(t)\right)\cdot(k1\cdot t\cdot u(t-t1))=\frac{-k1\cdot A1}{B1}\cdot e^{B1\cdot t}\cdot\left(t\cdot e^{-B1\cdot t}-t1\cdot e^{-B1\cdot t}+\frac{1}{B1}\cdot e^{-B1\cdot t}-\frac{1}{B1}\cdot e^{-B1\cdot t1}\right)$$

$$\left(A1\cdot e^{B1\cdot t}*u(t)\right)\cdot(k1\cdot t\cdot u(t-t1))=\frac{-k1\cdot A1}{B1}\cdot\left[t-t1\cdot e^{B1\cdot(t-t1)}+\frac{1}{B1}-\frac{1}{B1}\cdot e^{B1\cdot(t-t1)}\right]\cdot u(t-t1)$$

next term ...

$$\left(A1\cdot e^{B1\cdot t}\cdot u(t)\right)*\left(\frac{k1}{P1}\cdot u(t-t1)\right)=\frac{-A1\cdot k1}{P1}\cdot\int_{t1}^{t} e^{B1\cdot(t-\tau)}\,d\tau$$

$$\left(A1\cdot e^{B1\cdot t}\cdot u(t)\right)*\left(\frac{k1}{P1}\cdot u(t-t1)\right)=\frac{-A1\cdot k1}{P1}\cdot e^{B1\cdot t}\cdot\int_{t1}^{t} e^{-B1\cdot\tau}\,d\tau$$

$$\left(A1\cdot e^{B1\cdot t}\cdot u(t)\right)*\left(\frac{k1}{P1}\cdot u(t-t1)\right)=\frac{-A1\cdot k1}{P1\cdot B1}\cdot e^{B1\cdot t}\cdot e^{-B1\cdot\tau} \quad \text{evaluated from t1 to t}$$

$$\left(A1\cdot e^{B1\cdot t}\cdot u(t)\right)*\left(\frac{k1}{P1}\cdot u(t-t1)\right)=\frac{-A1\cdot k1}{P1\cdot B1}\cdot e^{B1\cdot t}\cdot\left(e^{-B1\cdot t}-e^{-B1\cdot t1}\right)$$

$$\left(A1\cdot e^{B1\cdot t}\cdot u(t)\right)*\left(\frac{k1}{P1}\cdot u(t-t1)\right)=\frac{-A1\cdot k1}{P1\cdot B1}\cdot\left[1-e^{B1\cdot(t-t1)}\right]\cdot u(t-t1)$$

next term...

$$\left(A1\cdot e^{B1\cdot t}\cdot u(t)\right)*\left(\frac{-k1}{P1}\cdot e^{P1\cdot t}\cdot u(t-t1)\right)=\frac{-A1\cdot k1}{P1}\cdot\int_{t1}^{t} e^{P1\cdot\tau}\cdot e^{B1\cdot(t-\tau)}\,d\tau$$

$$\left(A1\cdot e^{B1\cdot t}\cdot u(t)\right)*\left(\frac{-k1}{P1}\cdot e^{P1\cdot t}\cdot u(t-t1)\right)=\frac{-A1\cdot k1}{P1}\cdot e^{B1\cdot t}\cdot\int_{t1}^{t} e^{(P1-B1)\cdot\tau}\,d\tau$$

$$\left(A1\cdot e^{B1\cdot t}\cdot u(t)\right)*\left(\frac{-k1}{P1}\cdot e^{P1\cdot t}\cdot u(t-t1)\right)=\frac{-A1\cdot k1\cdot e^{B1\cdot t}}{P1\cdot(P1-B1)}\cdot e^{(P1-B1)\cdot\tau} \quad \text{evaluated from t1 to t}$$

$$\left(A1\cdot e^{B1\cdot t}\cdot u(t)\right)*\left(\frac{-k1}{P1}\cdot e^{P1\cdot t}\cdot u(t-t1)\right)=\frac{-A1\cdot k1}{P1\cdot(P1-B1)}\cdot e^{B1\cdot t}\cdot\left[e^{(P1-B1)\cdot t}-e^{(P1-B1)\cdot t1}\right]$$

$$\left(A1\cdot e^{B1\cdot t}\cdot u(t)\right)*\left(\frac{-k1}{P1}\cdot e^{P1\cdot t}\cdot u(t-t1)\right)=\frac{-A1\cdot k1}{P1\cdot(P1-B1)}\cdot\left[e^{P1\cdot t}-e^{P1\cdot t1}\cdot e^{B1\cdot(t-t1)}\right]\cdot u(t-t1)$$

The next set of terms ….

$$\left(A2\cdot e^{B2\cdot t}\cdot u(t)\right)\ast\left(k1\cdot t\cdot u(t-t1)\right)=k1\cdot A2\cdot\int_{t1}^{t}\tau e^{-B2\cdot(t-\tau)}\,d\tau$$

$$\left(A2\cdot e^{B2\cdot t}\cdot u(t)\right)\ast\left(k1\cdot t\cdot u(t-t1)\right)=\frac{-k1\cdot A2}{B2}\cdot e^{B2\cdot t}\cdot\int_{t1}^{t}\tau\,d\,e^{-B2\cdot\tau}$$

$$\left(A2\cdot e^{B2\cdot t}\cdot u(t)\right)\ast\left(k1\cdot t\cdot u(t-t1)\right)=\frac{-k1\cdot A2}{B2}\cdot e^{B2\cdot t}\cdot\left(\tau e^{-B2\cdot\tau}-\int_{\tau 1}^{\tau}e^{-B2\cdot\tau}\,d\tau\right)$$

$$\left(A2\cdot e^{B2\cdot t}\cdot u(t)\right)\ast\left(k1\cdot t\cdot u(t-t1)\right)=\frac{-k1\cdot A2}{B2}\cdot e^{B2\cdot t}\cdot\left(\tau e^{-B2\cdot\tau}+\frac{1}{B2}\cdot e^{-B2\cdot\tau}\right)\quad\text{evaluated from t1 to t}$$

$$\left(A2\cdot e^{B2\cdot t}\cdot u(t)\right)\ast\left(k1\cdot t\cdot u(t-t1)\right)=\frac{-k1\cdot A2}{B2}\cdot e^{B2\cdot t}\cdot\left(t\cdot e^{-B2\cdot t}-t1\cdot e^{-B2\cdot t}+\frac{1}{B2}\cdot e^{-B2\cdot t}-\frac{1}{B2}\cdot e^{-B2\cdot t1}\right)$$

$$\left(A2\cdot e^{B2\cdot t}\cdot u(t)\right)\ast\left(k1\cdot t\cdot u(t-t1)\right)=\frac{-k1\cdot A2}{B2}\cdot\left[t-t1\cdot e^{B2\cdot(t-t1)}+\frac{1}{B2}-\frac{1}{B2}\cdot e^{B2\cdot(t-t1)}\right]\cdot u(t-t1)$$

next term...

$$\left(A2\cdot e^{B2\cdot t}\cdot u(t)\right)\ast\left(\frac{k1}{P1}\cdot u(t-t1)\right)=\frac{+A2\cdot k1}{P1}\cdot\int_{t1}^{t}e^{B2\cdot(t-\tau)}\,d\tau$$

$$\left(A2\cdot e^{B2\cdot t}\cdot u(t)\right)\ast\left(\frac{k1}{P1}\cdot u(t-t1)\right)=\frac{+A2\cdot k1}{P1}\cdot e^{B2\cdot t}\cdot\int_{t1}^{t}e^{-B2\cdot\tau}\,d\tau$$

$$\left(A2\cdot e^{B2\cdot t}\cdot u(t)\right)\ast\left(\frac{k1}{P1}\cdot u(t-t1)\right)=\frac{-A2\cdot k1}{P1\cdot B2}\cdot e^{B2\cdot t}\cdot e^{-B2\cdot\tau}\quad\text{evaluated from t1 to t}$$

$$\left(A2\cdot e^{B2\cdot t}\cdot u(t)\right)\ast\left(\frac{k1}{P1}\cdot u(t-t1)\right)=\frac{-A2\cdot k1}{P1\cdot B2}\cdot e^{B2\cdot t}\cdot\left(e^{-B2\cdot t}-e^{-B2\cdot t1}\right)$$

$$\left(A2\cdot e^{B2\cdot t}\cdot u(t)\right)\ast\left(\frac{k1}{P1}\cdot u(t-t1)\right)=\frac{-A2\cdot k1}{P1\cdot B2}\cdot\left[1-e^{B2\cdot(t-t1)}\right]\cdot u(t-t1)$$

and finally, the last term...

$$\left(A2\cdot e^{B2\cdot t}\cdot u(t)\right)*\left(\frac{-k1}{P1}\cdot e^{P1\cdot t}\cdot u(t-t1)\right)=\frac{-A2\cdot k1}{P1}\cdot\int_{t1}^{t} e^{P1\cdot\tau}\cdot e^{B2\cdot(t-\tau)}\,d\tau$$

$$\left(A2\cdot e^{B2\cdot t}\cdot u(t)\right)*\left(\frac{-k1}{P1}\cdot e^{P1\cdot t}\cdot u(t-t1)\right)=\frac{-A2\cdot k1}{P1}\cdot e^{B2\cdot t}\cdot\int_{t1}^{t} e^{(P1-B2)\cdot\tau}\,d\tau$$

$$\left(A2\cdot e^{B2\cdot t}\cdot u(t)\right)*\left(\frac{-k1}{P1}\cdot e^{P1\cdot t}\cdot u(t-t1)\right)=\frac{-A2\cdot k1\cdot e^{B2\cdot t}}{P1\cdot(P1-B2)}\cdot e^{(P1-B2)\cdot\tau} \quad \text{evaluated from t1 to t}$$

$$\left(A2\cdot e^{B2\cdot t}\cdot u(t)\right)*\left(\frac{-k1}{P1}\cdot e^{P1\cdot t}\cdot u(t-t1)\right)=\frac{-A2\cdot k1}{P1\cdot(P1-B2)}\cdot e^{B2\cdot t}\cdot\left[e^{(P1-B2)\cdot t}-e^{(P1-B2)\cdot t1}\right]$$

$$\left(A2\cdot e^{B2\cdot t}\cdot u(t)\right)*\left(\frac{-k1}{P1}\cdot e^{P1\cdot t}\cdot u(t-t1)\right)=\frac{-A2\cdot k1}{P1\cdot(P1-B2)}\cdot\left[e^{P1\cdot t}-e^{P1\cdot t1}\cdot e^{B2\cdot(t-t1)}\right]\cdot u(t-t1)$$

Put all that together and get the final equation

$$\begin{aligned}
Vout2(t)=K0\cdot K1\Bigg\{&\left[\left(t+\frac{1}{P1}\right)-\frac{1}{P1}\cdot e^{P1\cdot t}\right]\ldots\\
&+\frac{-K1\cdot A1}{B1}\cdot\left[t-t1\cdot e^{B1\cdot(t-t1)}+\frac{1}{B1}-\frac{1}{B1}\cdot e^{B1\cdot(t-t1)}\right]\ldots\\
&+\frac{-K1\cdot A2}{B2}\cdot\left[t-t1\cdot e^{B2\cdot(t-t1)}+\frac{1}{B2}-\frac{1}{B2}\cdot e^{B2\cdot(t-t1)}\right]\ldots\\
&+\frac{-A1\cdot K1}{P1\cdot B1}\cdot\left[1-e^{B1\cdot(t-t1)}\right]\ldots\\
&+\frac{-A1\cdot K1}{P1\cdot(P1-B1)}\cdot\left[e^{P1\cdot t}-e^{P1\cdot t1}\cdot e^{B1\cdot(t-t1)}\right]\ldots\\
&+\frac{-A2\cdot K1}{P1\cdot B2}\cdot\left[1-e^{B2\cdot(t-t1)}\right]\ldots\\
&+\frac{-A2\cdot K1}{P1\cdot(P1-B2)}\cdot\left[e^{P1\cdot t}-e^{P1\cdot t1}\cdot e^{B2\cdot(t-t1)}\right]\Bigg\}\, u(\tau-\tau_1)
\end{aligned}$$

Next a detection of a second termination device is determined. As stated above, although it is not a standard configuration, both a Half Ringer and a Premises Splitter may be present on the line at the same time. A determination of what times in the measurement sequence will these devices turn on needs to be performed. At time t = 0, both terminations are open circuits. At time = t1, the Half Ringer will turn on and the Premises Splitter will still be an open circuit. Time t1 is then only dependent on the output voltage from the artline (or subscribers loop). This is equivalent to a single device on the line. At time = t2, the Premises Splitter will turn on. Time t2 is then dependent on both the output voltage from the artline and the voltage across the line after the Half Ringer turns on.

First a determination of when the Half Ringer turns on is performed. The Half Ringer will start to conduct when the voltage across it equals -2.9 volts. The Half Ringer zener diodes will turn on reversed at -2.4 volts and forward at -0.5 volts.

$$T := 0.5 \qquad R1 := 9.676649 \cdot 10^{1} \qquad P1 := -9.676649 \cdot 10^{1}$$

$$Vo(t) := 60 \cdot \frac{R1}{P1 \cdot T} \cdot \left(t + \frac{1}{P1} - \frac{1}{P1} \cdot e^{P1 \cdot t} \right)$$

$$-2.9 = 60 \cdot \frac{9.676649 \cdot 10^{1}}{-9.676649 \cdot 10^{1} \cdot 0.5} \cdot \left(t + \frac{1}{-9.676649 \cdot 10^{1}} - \frac{1}{-9.676649 \cdot 10^{1}} \cdot e^{-9.676649 \cdot 10^{1} \cdot t} \right)$$

$$t = \begin{bmatrix} 3.41203148250621104 32 \cdot 10^{-2} \\ -1.6496632318134759681 \cdot 10^{-2} \end{bmatrix}$$

The negative root is obviously not correct so the time that the the Half Ringer starts to conduct is :

$$t1 := 3.4120314825062110432 \cdot 10^{-2}$$

Redefined time as t1 for the rest of the analysis.

Now the turn on time of the Premises Splitter can be found. Using a turn on voltage of 6.4 volts and a forward drop of 0.5 volts for the zener diodes of the Premises Splitter, a determination can be made as to at what time will the output voltage of the artline be -6.9 volts.

$$K0 := 0.9969$$

$$K1 := \frac{60 \cdot R1}{P1 \cdot T}$$

$$K1 = -120 \qquad t1 := 3.412031482506211043 2 \cdot 10^{-2}$$

$$A1 := -118.8845 \qquad A2 := 12.6983 \qquad P1 := -9.676649 \cdot 10^{1}$$

$$B1 := -242.0485 \qquad B2 := -25.692 \qquad R1 := 96.766$$

$$\begin{aligned} time := root\Bigg[& \left[K0 \cdot K1 \cdot \left(t + \frac{1}{P1} - \frac{1}{P1} \cdot e^{P1 \cdot t}\right)\right] \ldots \\ & + \left[\frac{-K1 \cdot A1}{B1} \cdot \left[t - t1 \cdot e^{B1 \cdot (t - t1)} + \frac{1}{B1} - \frac{1}{B1} \cdot e^{B1 \cdot (t - t1)}\right]\right] \ldots \\ & + \left[\frac{-K1 \cdot A2}{B2} \cdot \left[t - t1 \cdot e^{B2 \cdot (t - t1)} + \frac{1}{B2} - \frac{1}{B2} \cdot e^{B2 \cdot (t - t1)}\right]\right] \ldots \\ & + \left[\frac{-A1 \cdot K1}{P1 \cdot B1} \cdot \left[1 - e^{B1 \cdot (t - t1)}\right]\right] \ldots \\ & + \left[\frac{-A1 \cdot K1}{P1 \cdot (P1 - B1)} \cdot \left[e^{P1 \cdot t} - e^{P1 \cdot t1} \cdot e^{B1 \cdot (t - t1)}\right]\right] \ldots \\ & + \left[\frac{-A2 \cdot K1}{P1 \cdot B2} \cdot \left[1 - e^{B2 \cdot (t - t1)}\right]\right] \ldots \\ & + \left[\frac{-A2 \cdot K1}{P1 \cdot (P1 - B2)} \cdot \left[e^{P1 \cdot t} - e^{P1 \cdot t1} \cdot e^{B2 \cdot (t - t1)}\right]\right] + 6.9 \quad , t \Bigg] \end{aligned}$$

$$time = 0.082887$$

The premises splitter is calculated to turn on at about 82.9 milliseconds. This corresponds to the 80.56 milliseconds in the early simulations. This is acceptable error (2.8%) as the math derivation is quite complex and there will be some error in the calculations for the constants.

The Drive Voltage can also be calculated by determining what is the input voltage to the artline at 82.89 milliseconds.

$$Vi(t) := -60 \cdot \frac{time}{T}$$

$$Vi(t) = -9.94639$$

The calculated value of -9.95 is again close to the -9.66 volts of the simulation. Since the time error was on the high side of simulated time, it would make sense that the calculated drive voltage error (2.9%) was also a little bit high.

Next an example of a line test will be described. The analysis shown so far is an ideal analysis and only partly describes what really happens during the ramp sequence. The Half Ringer, Premises Splitter, Electronic Ringer, Mechanical Ringer and the artline are charge storage devices. That is, since all of these devices contain capacitive elements, they will retain a charge once the stimulus is removed from the line under test. The analysis shown above assumed that all of the charge storage devices have zero charge at time = t.. During actual testing of a subscribers loop, it cannot be assumed that the devices on the line under test have zero charge. For this reason, it is necessary to precondition the line before the ramp technique is executed. By conditioning the line under test, a known charge can be placed on all of the devices on the subscribers loop. If a voltage can be placed on the line under test that is greater than the breakover voltages of devices that could be on the line, then any capacitors in that device would be charged. Then if the line was discharged, the nonlinear devices would retain a charge that is proportional to the breakover voltages of the active components in that device.

A circuit having a Half Ringer at the end of a subscriber's loop will be described as an example. A voltage equal to -50 volts is placed across a Half Ringer. After a time, the capacitance of the line under test will be fully charged and the capacitor of the Half Ringer will be charged to a value of near -50 volts (a capacitor will cease to draw current when it is fully charged and will become an open circuit). The line under test is discharged by driving with ground at both the Tip and Ring sides. The line under test and the Half Ringer capacitor will discharge as long as current flows. But, the zener diodes will turn off when the voltage drops below the breakover voltage. When the zeners stop conducting (approximately 2.7v + 0.5v = 3.2v) there will still be about 3.2 volts retained in the capacitor. This charge will stay in the capacitor indefinitely (assuming an ideal capacitor with no leakage). Note that in this example when the line under test is driven at ground potential that two things happened. First, if a Half Ringer was present, it would have a known charge. Also, the capacitance of the line under test was discharged completely. The line under test is now preconditioned, that is, the copper line is fully discharged and the Half Ringer device (if present) would have a known charge.

The analysis assumes zero charge across the capacitors. It has been shown that if the line under test is properly conditioned, the charge present across any storage device will be proportional to the zener diode breakover value of that device. Therefore, for each of the different network terminating devices (Half Ringer, etc.) it will take twice the zener

voltage breakover voltage in order for these devices to start conducting current. The Half Ringer has a zener breakover voltage of about 3.2 volts. After conditioning, the capacitor within the Half Ringer is charged to approximately 3.2 volts. Therefore in order for the Half Ringer to start conducting, the applied voltage must be at least 3.2 volts above the charge sitting across the capacitor in order to place 3.2 volts across the zeners. This means that the voltage across the Half Ringer now needs to be 6.4 volts (or double the 3.2 volt breakover voltage) before current will start to flow. The same preconditioning applies to all termination devices that contain nonlinear devices and charge storage devices. Unless a known charge is present in these devices, it is difficult to identify these devices. These devices include but are not limited to the Half Ringer, Premises Splitter, and Electronic Ringer. Devices such as the CO Splitter are not subject to preconditioning as it has no charge storage device (capacitor). The Mechanical Ringer is also exempt from preconditioning as it has no nonlinear devices (zener diodes).

The example just shown describes how a line test could be performed that will allow for detection of nonlinear devices on the line and how the test system could adjust the measurement results based on the detection of these devices to determine the presence of a linear devices such as a mechanical ringer. The example just shown is but one way to analyze a subscribers loop.

Having described preferred embodiments of the invention it will now become apparent to those of ordinary skill in the art that other embodiments incorporating these concepts may be used. Accordingly, it is submitted that that the invention should not be limited to the described embodiments but rather should be limited only by the spirit and scope of the appended claims.

What is claimed is

1. A measurement system comprising:

a voltage source capable of providing a ramped output voltage;

a ring side source resistance having a first end and a second end, the first end in electrical communication with an output of said voltage source, the second end capable of being coupled to a ring line;

a tip side source resistance having a first end and a second end, the first end in communication with a reference voltage, the second end capable of being coupled to a tip line; and

a differential amplifier having a first input coupled to the first end of said ring side source resistance, having a second input coupled to the second end of said ring side source resistance, and having an output indicating a presence of a termination between said ring line and said tip line.

2. The measurement system of claim 1 further comprising a differentiator having an input coupled to the output of said differential amplifier, an output of said differentiator indicating a presence of a termination between said ring line and said tip line.

3. The measurement system of claim 2 further comprising a gain stage having an input coupled to the output of said differentiator, an output of said gain stage indicating a presence of a termination between said ring line and said tip line.

4. The measurement apparatus of claim 1 wherein said termination between said ring line and said tip line is selected from the group consisting of a central office splitter, a half ringer, a premises splitter and an electronic ringer.

5. The measurement system of claim 1 wherein said ramped output voltage comprises a voltage ramping from approximately zero volts to approximately ±100 volts.

6. The measurement system of claim 5 wherein said ramped voltage goes from approximately zero volts to approximately ±100 volts in less than or equal to approximately one second.

7. The measurement system of claim 1 wherein said ring side source resistance has a value between approximately one hundred ohms and approximately twenty thousand ohms.

8. The measurement system of claim 1 wherein said tip side source resistance has a value between approximately one hundred ohms and approximately twenty thousand ohms.

9. A method of detecting the presence of a termination on a telephone line comprising the steps of:

providing a voltage source producing a ramped output voltage;

coupling a ring side source resistance between an output of said voltage source and a ring line of a selected telephone line;

coupling a tip side source resistance between a reference voltage and a tip line of the selected telephone line;

measuring a differential voltage across said ring side source resistance; and

outputting a signal indicating a presence of a termination between said ring line and said tip line.

10. The method of claim 9 further comprising the step of differentiating the voltage measured across said ring side source resistance.

11. The method of claim 10 further comprising the step of amplifying an output of said step of differentiating.

12. The method of claim 9 wherein said step of outputting a signal comprises the step of outputting a signal indicting a presence of at least one of a central office splitter, a half-ringer, a premises splitter and an electronic ringer.

13. The method of claim 9 wherein said step of providing a voltage source comprises the step of providing a voltage source producing a voltage ramping from approximately zero volts to approximately ±100 volts.

14. The method of claim 13 wherein said step of providing a voltage source comprises the step of providing a voltage source producing a voltage ramping from

approximately zero volts to approximately ±100 volts in less than or equal to approximately one second.

15. The method of claim 9 wherein said step of coupling a ring side source resistance comprises coupling a ring side source resistance having a value between approximately one hundred ohms and approximately twenty thousand ohms.

16. The method of claim 11 wherein said step of coupling a tip side source resistance comprises coupling a tip side source resistance having a value between approximately one hundred ohms and approximately twenty thousand ohms.

17. The method of claim 9 further comprising the step of preconditioning the telephone line before said step of providing a voltage source.

18. The method of claim 17 wherein said step of preconditioning comprises the steps of:

placing a voltage across said telephone line sufficient to fully charge a capacitance on said line; and

discharging said telephone line.

19. The method of claim 18 wherein said step of discharging comprises grounding said tip line and said ring line of said telephone line.

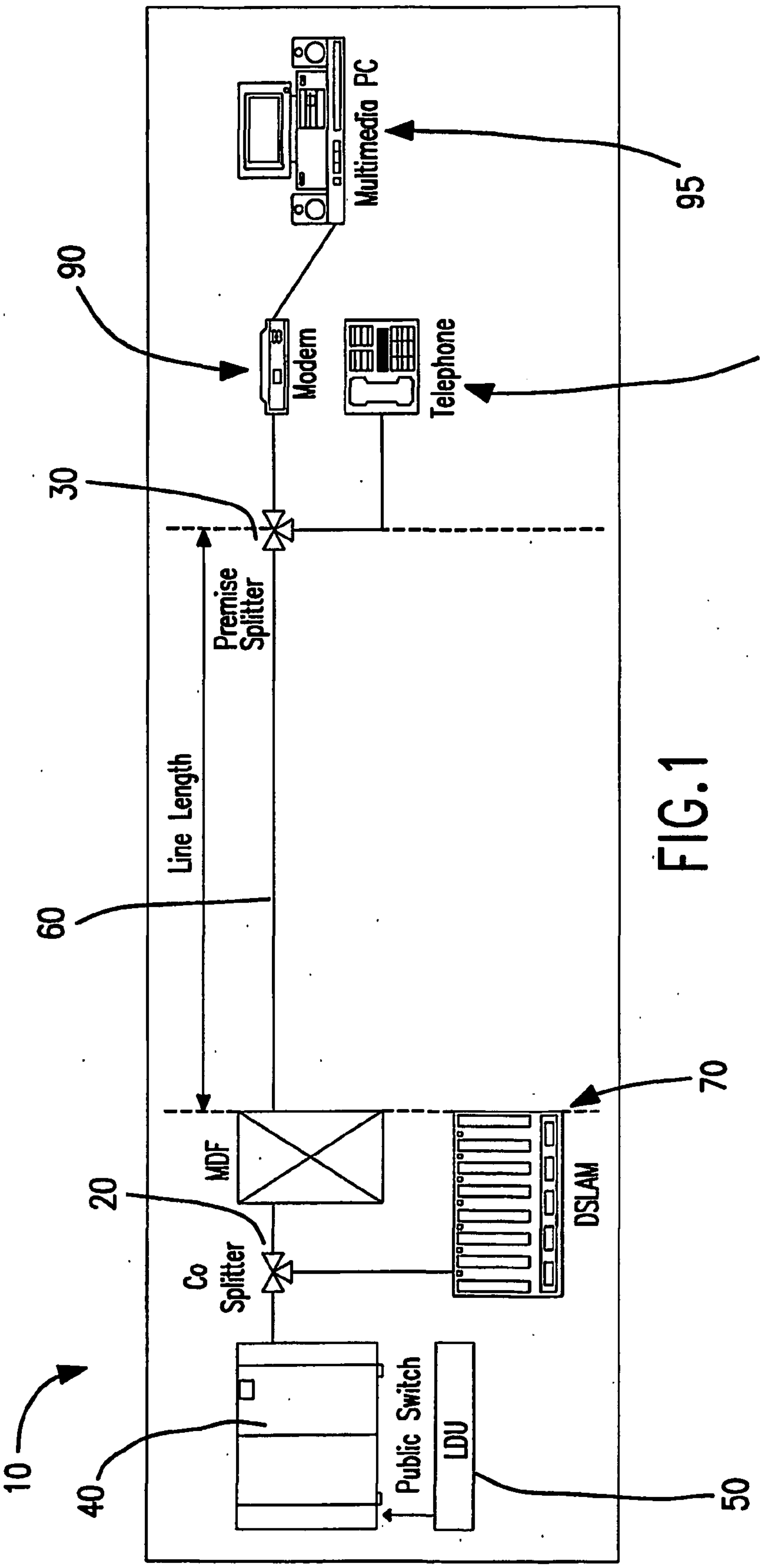
Multimedia PC
95
90
Modem
Telephone
80
30
Premise Splitter
Line Length
60
70
MDF
DSLAM
20
Co Splitter
10
40
Public Switch
LDU
50

FIG. 1

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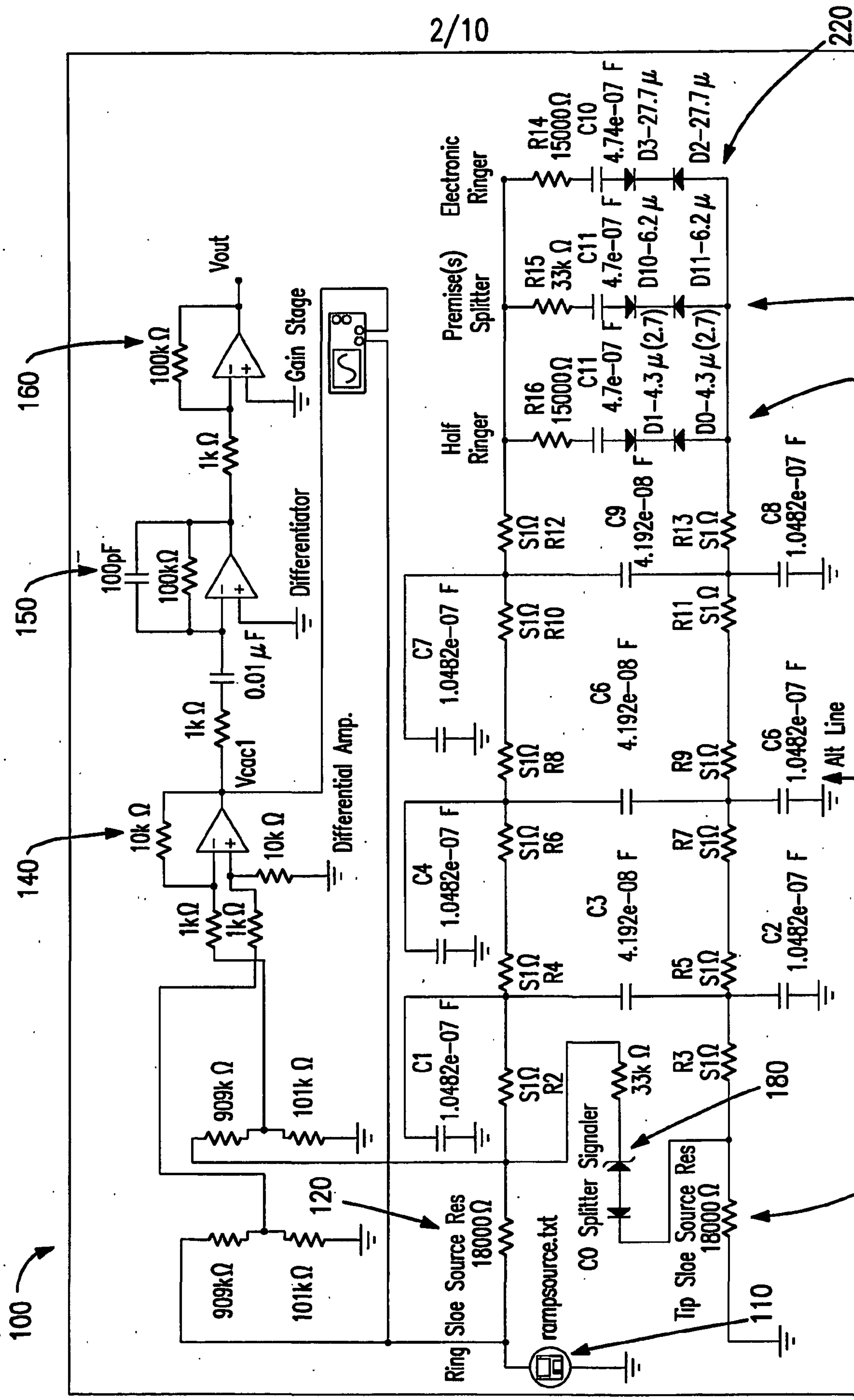
Vout
Gain Stage
100kΩ
1kΩ
Differentiator
100pF
100kΩ
0.01μF
Vcac1
Differential Amp.
10k Ω
1kΩ
909kΩ
101kΩ
Ring Sloe Source Res
18000Ω
rampsource.txt
CO Splitter Signaler
33k Ω
Tip Sloe Source Res
18000Ω
C1 1.0482e-07 F
C2 1.0482e-07 F
C3 4.192e-08 F
C4 1.0482e-07 F
C6 4.192e-08 F
C6 1.0482e-07 F
C7 1.0482e-07 F
C8 1.0482e-07 F
C9 4.192e-08 F
R2 S1Ω
R3 S1Ω
R4 S1Ω
R5 S1Ω
R6 S1Ω
R7 S1Ω
R8 S1Ω
R9 S1Ω
R10 S1Ω
R11 S1Ω
R12 S1Ω
R13 S1Ω
Alt Line
Half Ringer
Premise(s) Splitter
Electronic Ringer
R16 15000Ω
C11 4.7e-07 F
D1-4.3μ(2.7)
D0-4.3μ(2.7)
R15 33k Ω
C11 4.7e-07 F
D10-6.2μ
D11-6.2μ
R14 15000Ω
C10 4.74e-07 F
D3-27.7μ
D2-27.7μ
100
110
120
130
140
150
160
170
180
190
200
220

FIG.2

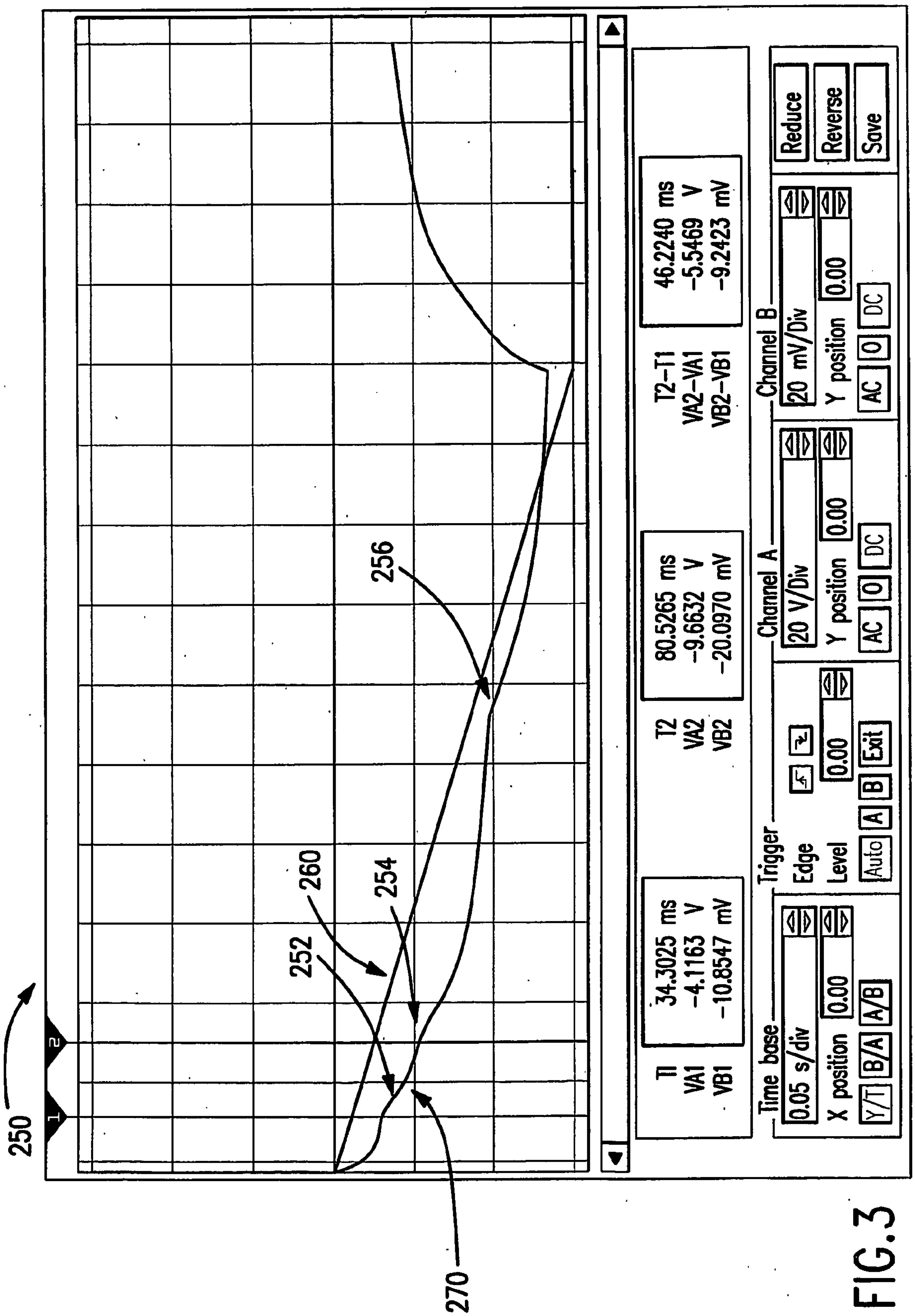
250
252
254
256
260
270
T1 34.3025 ms
VA1 -4.1163 V
VB1 -10.8547 mV
T2 80.5265 ms
VA2 -9.6632 V
VB2 -20.0970 mV
T2-T1 46.2240 ms
VA2-VA1 -5.5469 V
VB2-VB1 -9.2423 mV
Time base
0.05 s/div
X position 0.00
Y/T B/A A/B
Trigger
Edge
Level 0.00
Auto A B Exit
Channel A
20 V/Div
Y position 0.00
AC 0 DC
Channel B
20 mV/Div
Y position 0.00
AC 0 DC
Reduce
Reverse
Save

FIG.3

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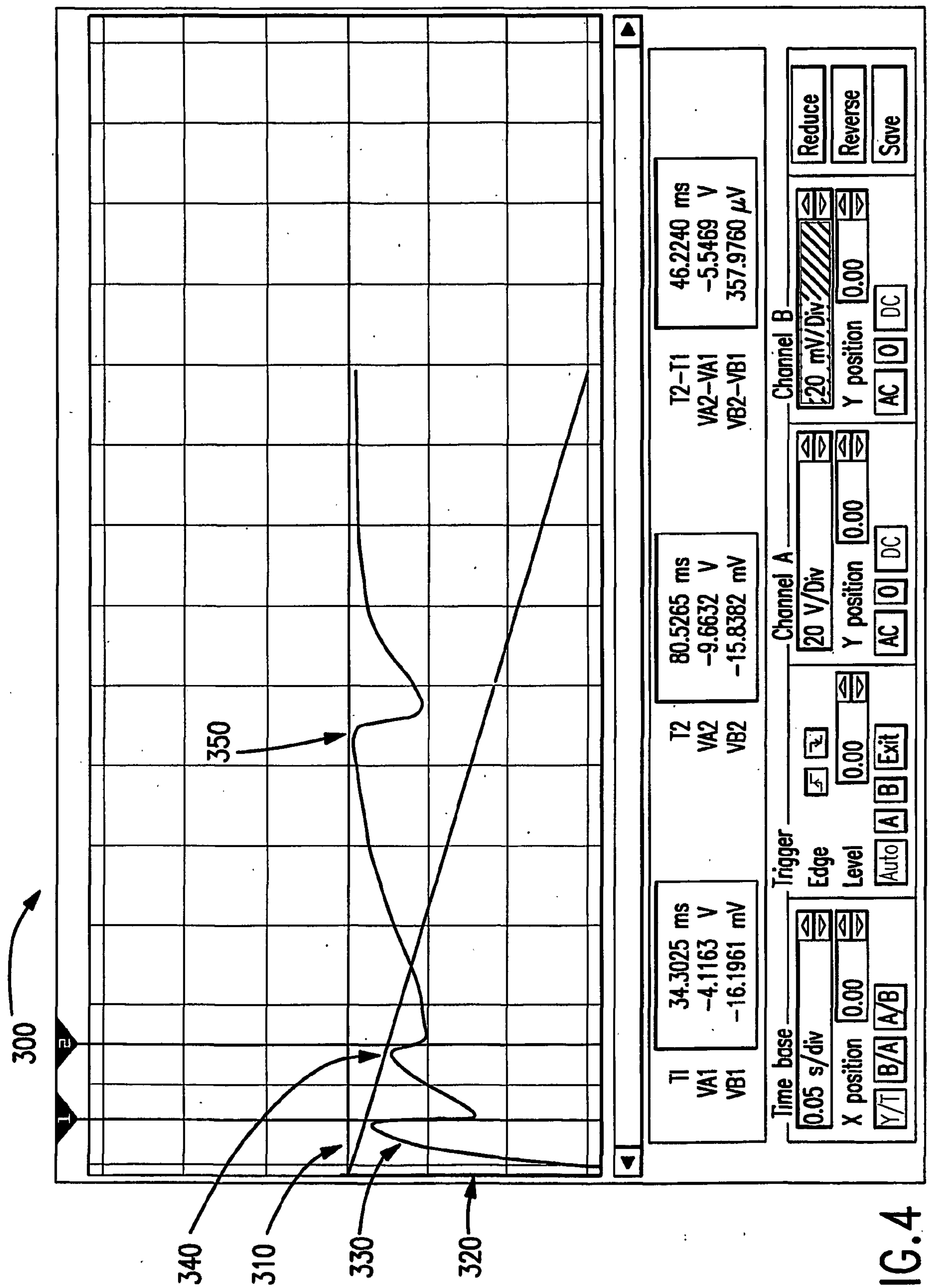

300
350
340
310
330
320
T1 34.3025 ms
VA1 -4.1163 V
VB1 -16.1961 mV
T2 80.5265 ms
VA2 -9.6632 V
VB2 -15.8382 mV
T2-T1 46.2240 ms
VA2-VA1 -5.5469 V
VB2-VB1 357.9760 μV
Time base
0.05 s/div
X position 0.00
Y/T B/A A/B
Trigger
Edge
Level 0.00
Auto A B Exit
Channel A
20 V/Div
Y position 0.00
AC 0 DC
Channel B
20 mV/Div
Y position 0.00
AC 0 DC
Reduce
Reverse
Save

FIG.4

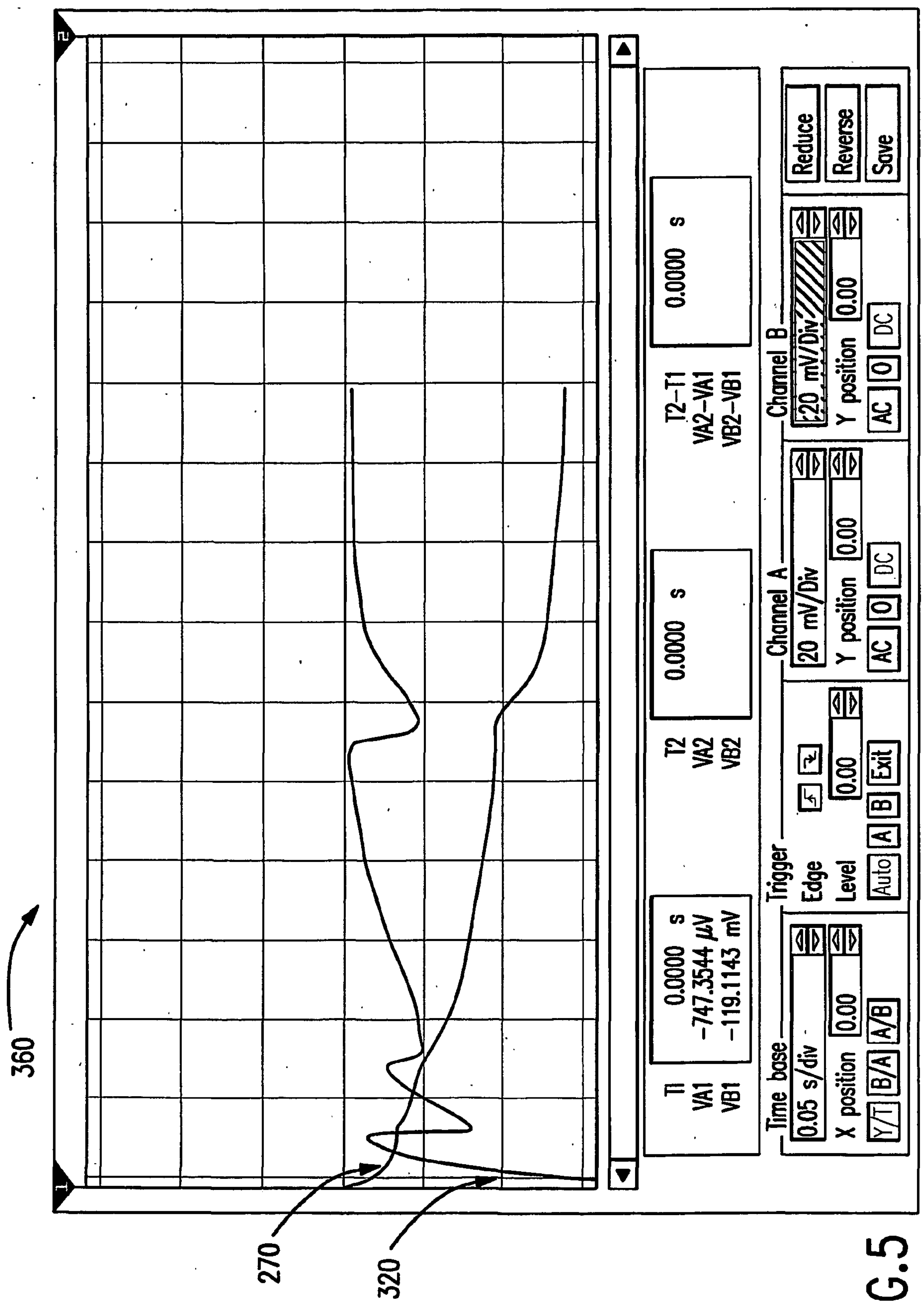

360
270
320
T1
VA1
VB1
0.0000 s
-747.3544 μV
-119.1143 mV
T2
VA2
VB2
0.0000 s
T2-T1
VA2-VA1
VB2-VB1
0.0000 s
Time base
0.05 s/div
X position
0.00
Y/T
B/A
A/B
Trigger
Edge
Level
0.00
Auto
A
B
Exit
Channel A
20 mV/Div
Y position
0.00
AC
O
DC
Channel B
20 mV/Div
Y position
0.00
AC
O
DC
Reduce
Reverse
Save

FIG.5

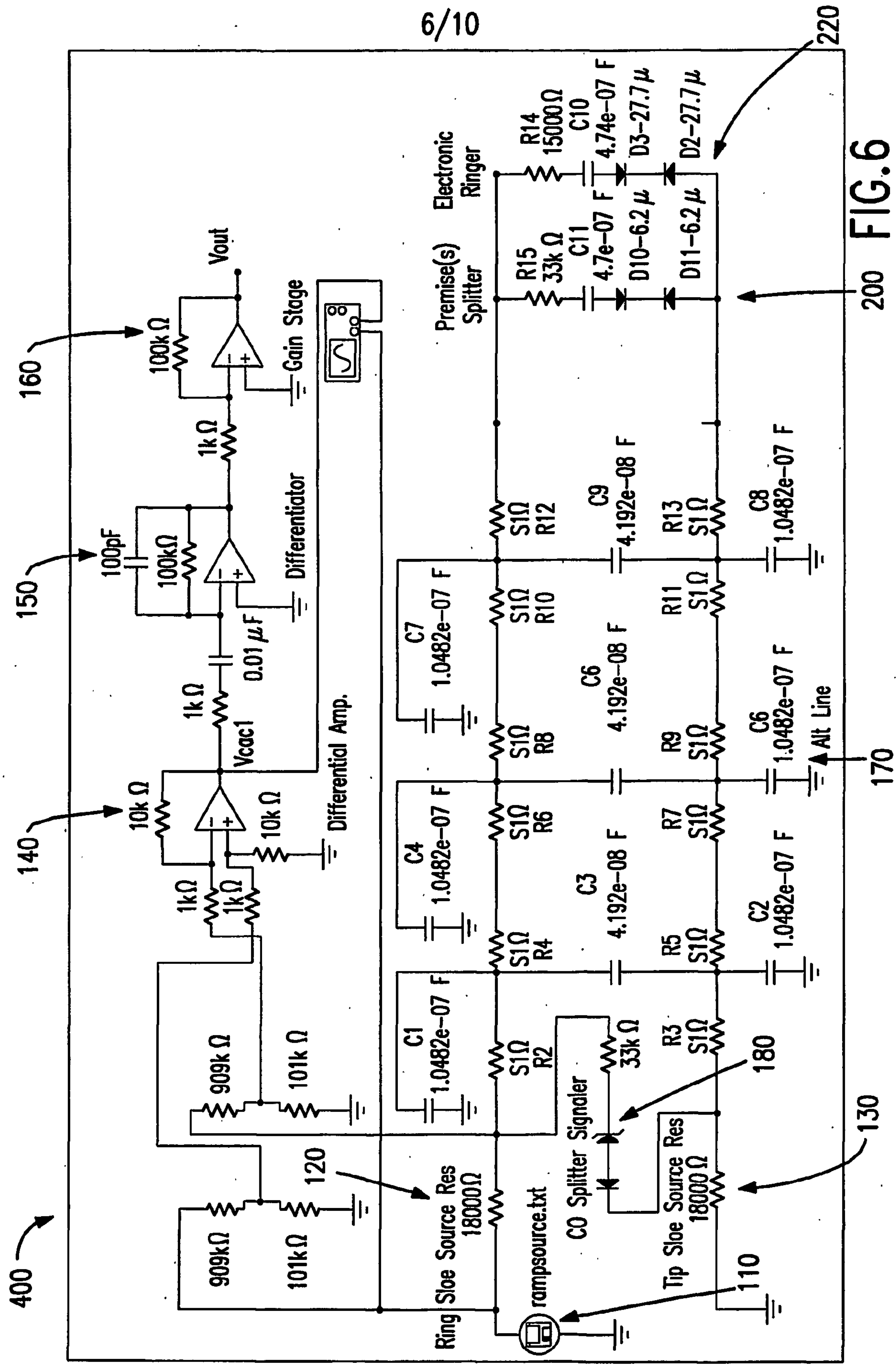
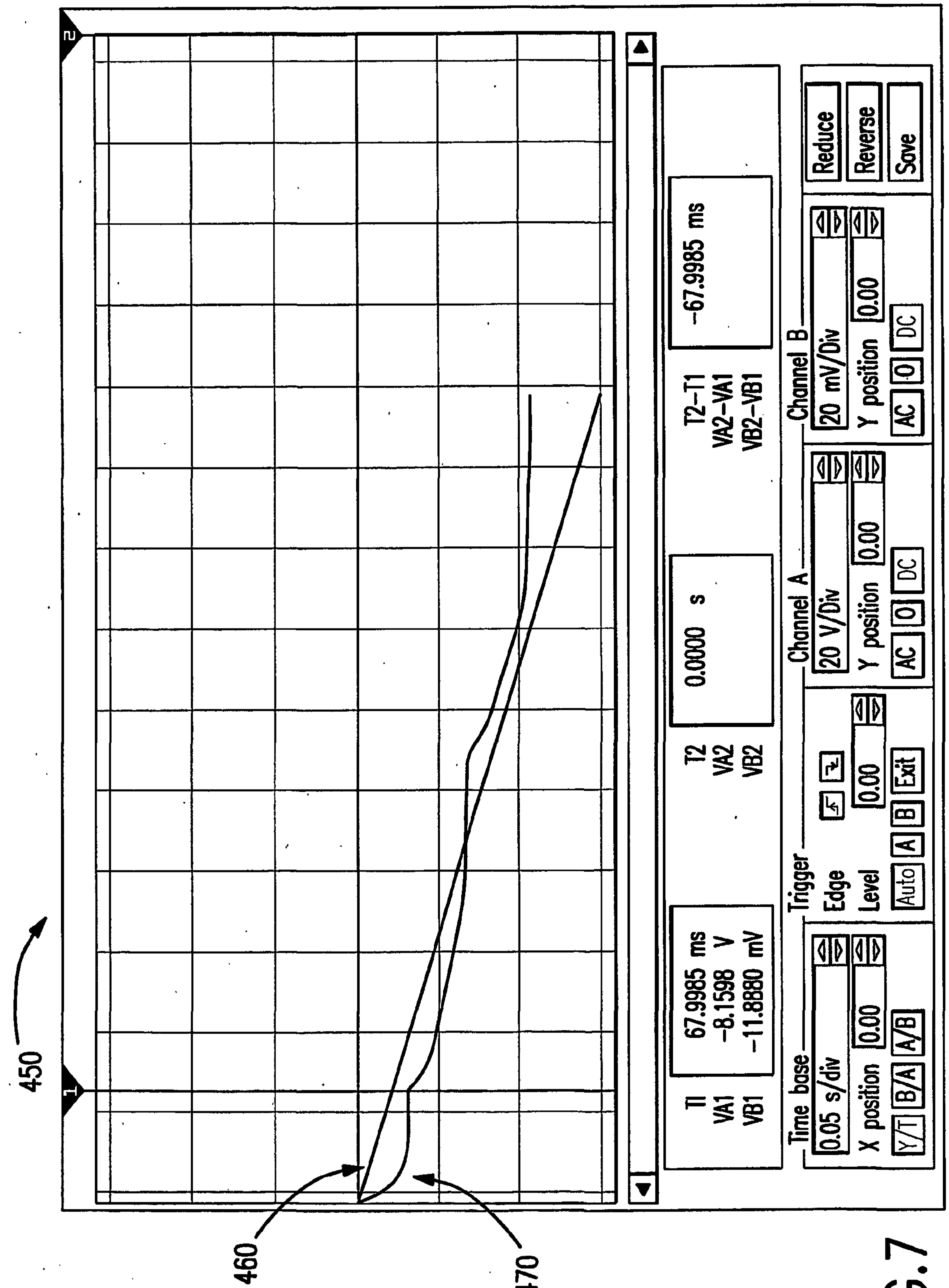

400
140
150
160
10k Ω
1k Ω
1k Ω
10k Ω
Differential Amp.
Vcac1
1k Ω
0.01 μF
100pF
100kΩ
Differentiator
1k Ω
100k Ω
Gain Stage
Vout
909kΩ
101kΩ
909k Ω
101k Ω
120
Ring Sloe Source Res
1800Ω
rampsource.txt
110
CO Splitter Signaler
180
33k Ω
Tip Sloe Source Res
1800Ω
130
C1
1.0482e-07 F
S1Ω
R2
R3
S1Ω
C4
1.0482e-07 F
S1Ω
R4
C3
4.192e-08 F
R5
S1Ω
C2
1.0482e-07 F
S1Ω
R6
R7
S1Ω
C6
1.0482e-07 F
Alt Line
170
S1Ω
R8
C6
4.192e-08 F
R9
S1Ω
C7
1.0482e-07 F
S1Ω
R10
R11
S1Ω
S1Ω
R12
C9
4.192e-08 F
R13
S1Ω
C8
1.0482e-07 F
Premise(s) Splitter
R15
33k Ω
C11
4.7e-07 F
D10-6.2 μ
D11-6.2 μ
200
Electronic Ringer
R14
1500Ω
C10
4.74e-07 F
D3-27.7 μ
D2-27.7 μ
220

FIG.6



450
460
470
1
2
T1
VA1
VB1
67.9985 ms
-8.1598 V
-11.8880 mV
T2
VA2
VB2
0.0000 s
T2-T1
VA2-VA1
VB2-VB1
-67.9985 ms
Time base
0.05 s/div
X position 0.00
Y/T B/A A/B
Trigger
Edge
Level
0.00
Auto A B Exit
Channel A
20 V/Div
Y position 0.00
AC 0 DC
Channel B
20 mV/Div
Y position 0.00
AC 0 DC
Reduce
Reverse
Save

FIG.7

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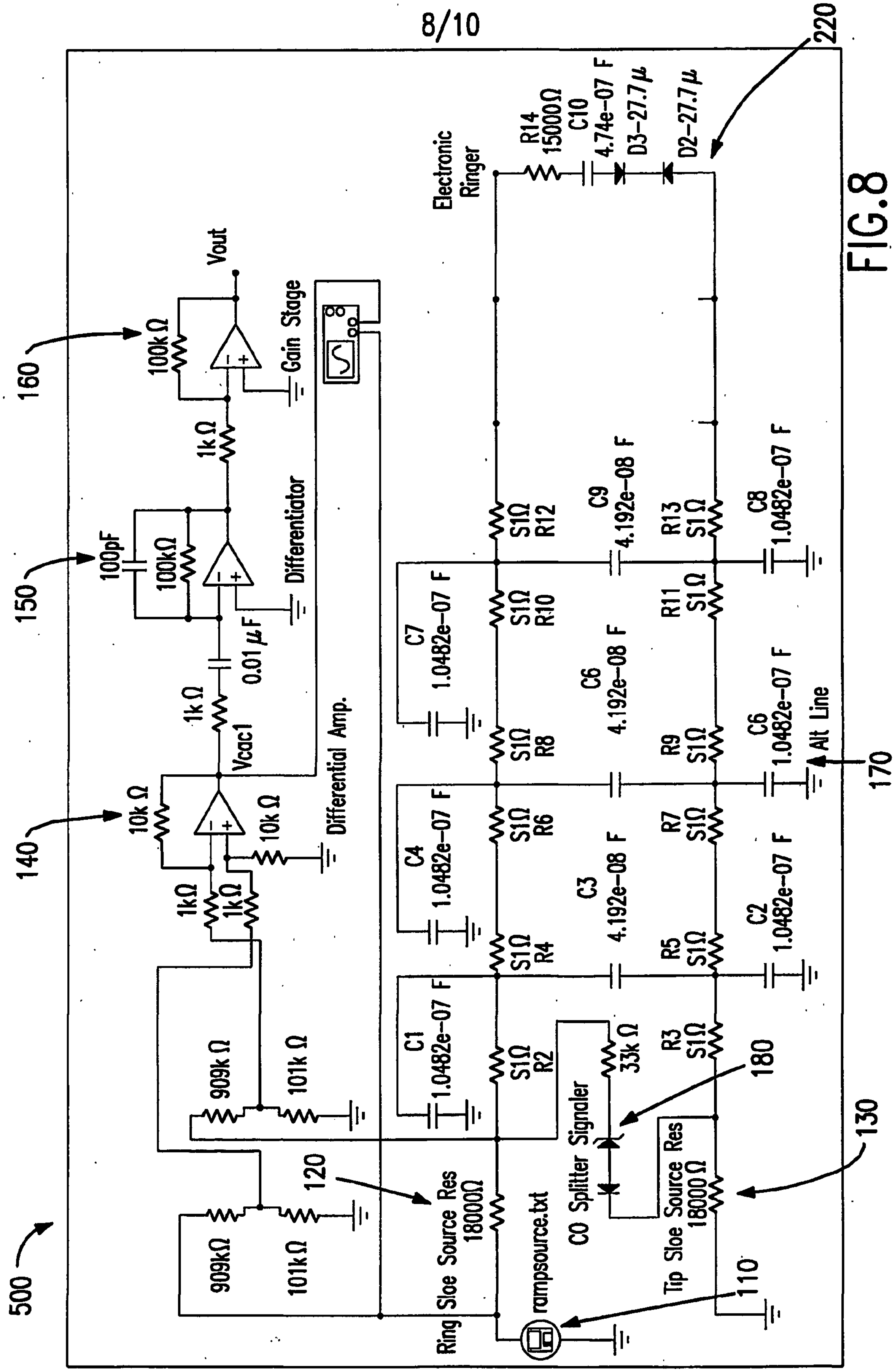

500
140
150
160
Vout
100kΩ
Gain Stage
1kΩ
100pF
100kΩ
Differentiator
0.01μF
Vcac1
10kΩ
Differential Amp.
909kΩ
101kΩ
120
Ring Sloe Source Res 18000Ω
rampsource.txt
110
CO Splitter Signaler
180
33kΩ
Tip Sloe Source Res 18000Ω
130
C1 1.0482e-07 F
C2 1.0482e-07 F
C3 4.192e-08 F
C4 1.0482e-07 F
C6 4.192e-08 F
C6 1.0482e-07 F
C7 1.0482e-07 F
C8 1.0482e-07 F
C9 4.192e-08 F
R2 S1Ω
R3 S1Ω
R4 S1Ω
R5 S1Ω
R6 S1Ω
R7 S1Ω
R8 S1Ω
R9 S1Ω
R10 S1Ω
R11 S1Ω
R12 S1Ω
R13 S1Ω
Alt Line
170
Electronic Ringer
R14 15000Ω
C10 4.74e-07 F
D3-27.7μ
D2-27.7μ
220

FIG.8

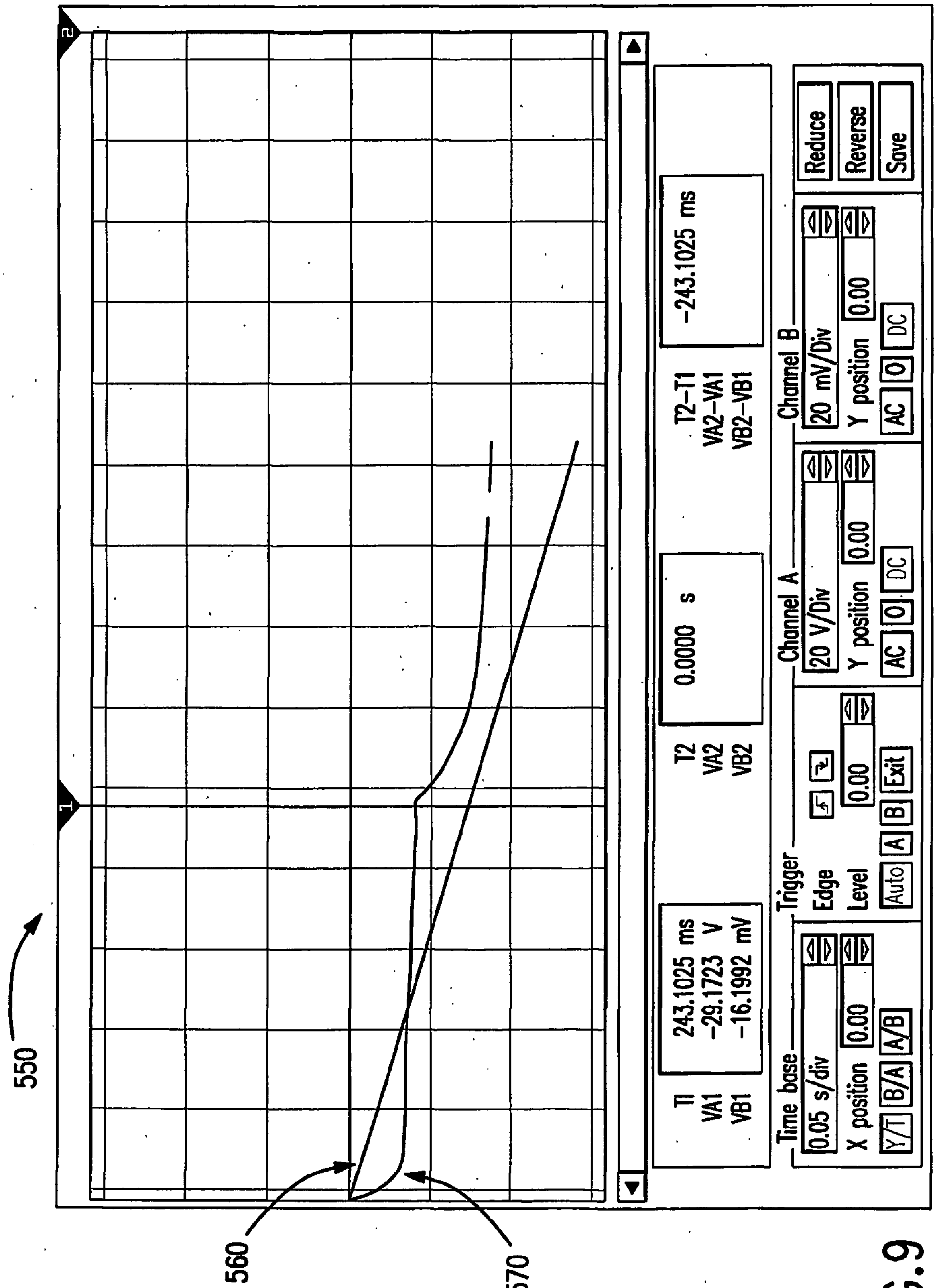
550
560
570
1
2
T1
VA1
VB1
243.1025 ms
-29.1723 V
-16.1992 mV
T2
VA2
VB2
0.0000 s
T2-T1
VA2-VA1
VB2-VB1
-243.1025 ms
Time base
0.05 s/div
X position
0.00
Y/T
B/A
A/B
Trigger
Edge
Level
0.00
Auto
A
B
Exit
Channel A
20 V/Div
Y position
0.00
AC
O
DC
Channel B
20 mV/Div
Y position
0.00
AC
O
DC
Reduce
Reverse
Save

FIG.9

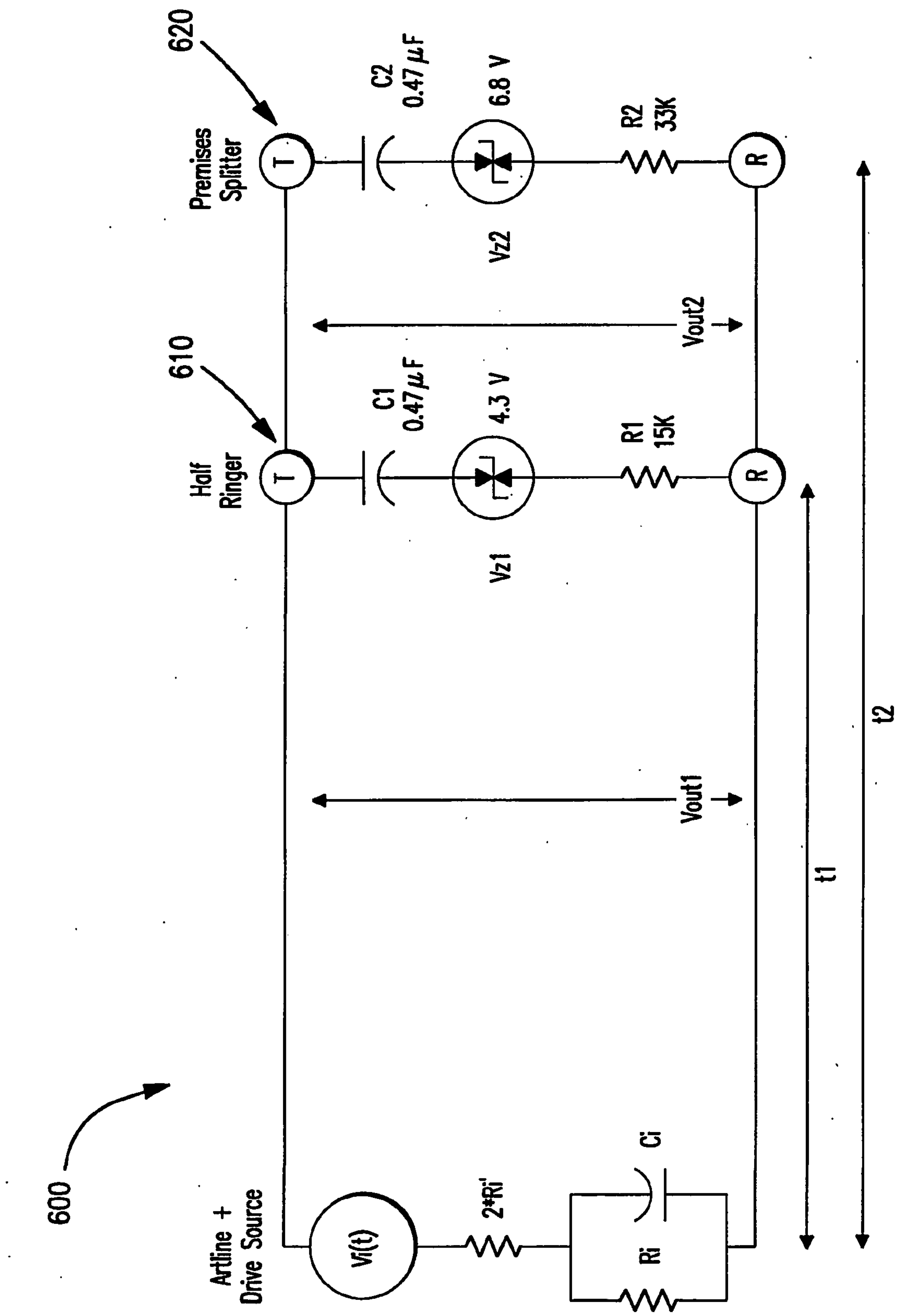
600
Artline + Drive Source
Vi(t)
2*Ri'
Ri
Ci
Half Ringer
610
T
C1 0.47μF
4.3 V
Vz1
R1 15K
R
Vout1
Premises Splitter
620
T
C2 0.47μF
6.8 V
Vz2
R2 33K
R
Vout2
t1
t2

FIG.10